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16. ABSTRACT

A program was conducted to design and develop a prototype mobile system for quick diversion of a stream flow around a contaminated area.

Spill scenarios were analyzed to establish design criteria for a self-contained, independent system that would maintain flow continuity around a region undergoing decontamination. The design utilized stock items available nationwide, to provide easy maintenance and replaceability. To provide flexibility and reliability, the system was assembled as two independent units, mounted on trailers so that spills would be readily accessible via state or interstate highways. A quick unloading feature provided capability for air shipment to more distant locations. Once onsite, the system could be assembled and placed in operation by a crew of five in a matter of hours.

Unit operation and ability to deliver a flow rate of 0.35 m^3/s a distance of 0.3 km over unprepared ground were evaluated in a shakedown test.

Alternative modes of operation have been defined and capabilities indicated. The system can deliver a flow rate of 0.09 m^3/s a nominal distance of 1 km, or a flow rate of 0.35 m^3/s a distance of 0.3 km.

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A MOBILE STREAM DIVERSION SYSTEM FOR HAZARDOUS MATERIALS SPILLS ISOLATION

by

James V. Zaccor
Scientific Service, Inc.
Redwood City, California 94063

Contract No. 68-03-2458

Project Officer

Frank J. Freestone
Oil and Hazardous Materials Spills Branch
Municipal Environmental Research Laboratory--Cincinnati
Edison, New Jersey 08817

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and integrated attach on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

Some types of environmental accidents have dynamic aspects that can lead to far-reaching as well as devastating consequences. This report describes a system developed to respond to one class of environmental accident - the spill of hazardous material into streams. Analyses and field experience have been applied to produce and demonstrate a quick-response prototype mobile stream diversion system to bypass normal stream flow around an isolated section of contaminated stream while the latter is being restored.

Francis T. Mayo, Director
Municipal Environmental Research Laboratory

ABSTRACT

This program was undertaken to design and develop a practical prototype mobile stream diversion system for quick diversion of a stream flow around a contaminated area.

Spill scenarios were analyzed to establish design criteria for a completely self-contained, independent system that would maintain flow continuity around a region undergoing decontamination processing. The system was designed to use stock items available nationwide, to be easily maintained, and to be readily replaceable. To provide flexibility and reliability, the system has been assembled as two totally independent units mounted on trailers so that spills will be readily accessible via state or interstate highways. Components are fastened on the trailers so they can be quickly unloaded for air shipment to more distant locations. Once onsite, the system can be assembled and placed in operation by a crew of five in a matter of hours.

Unit operation and ability to deliver a flow rate of 0.35 m^3/s (5,600 gpm) a distance of 0.3 km (1,000 ft) over unprepared ground were evaluated in a shakedown test.

Alternative modes of operation have been defined and capabilities indicated. The system can deliver a flow rate of 0.09 m^3/s (1,425 gpm) a nominal distance of 1 km (3,280 ft) or a flow rate of 0.35 m^3/s (5,600 gpm) a distance of 0.3 km (1,000 ft).

This report was submitted in fulfillment of Contract No. 68-03-2458 by Scientific Service, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period September 7, 1976, to August 31, 1977, and work was completed as of December 31, 1977.

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SECTION 1

INTRODUCTION

The spill response experience of the Hazardous Spills Staff of the Oil and Hazardous Materials Spills research group in Edison, N.J. have often included spill cleanup scenarios involving contamination of small streams by insoluble sinking hazardous materials. According to data from the U.S. Geological survey, approximately 84% of the stream-miles in the U.S. flow at 0.28 cubic meters per second (4,400 gallons per minute) or less. Further, an analysis of the proposed list of designated "hazardous substances" indicates that approximately 45% of the materials listed are either insoluble sinkers or form insoluble precipitates on contact with water.

Cleanup of insoluble sinkers from stream bottoms can be accomplished in several ways such as hand vacuuming or dredging. These techniques often lead to downstream spread of the contaminant due to resuspension of bottom muds and silts. Further, there are significant problems associated with treatment of the water-sediment slurry produced by the dredging. Another approach is to dam the stream where possbile above the impacted area and bypass the normal stream flow. This stream flow bypassing will permit the spill-impacted segment to dry, thus facilitating cleanup either manually or with mechanical earthmoving equipment. The problems of sediment resuspension and treatment of large volumes of contaminated dredge water are exchanged for the requirements of pumping and piping to achieve the bypass.

Other spill experiences have pointed out the need for rapidly, deployable pumping and piping to isolate a pond or bog that has been impacted by soluble materials. The slow movement of these materials makes the utilization of a diversion system practical.

For stream flows less than 0.0063 cubic meters per second (100 gallons per minute), it is sometimes possible to achieve bypass by gravity flow. Gravity bypasses, however, may have to be placed in the very stream bed that is to be the subject of the cleanup. For those stream flows that require pumping due to the combination of head and flow rate involved, suitable pumping and piping systems are not always readily at hand and valuable time is lost at the spill while attempting to engineer a system. Therefore, EPA's Edison spills research group undertook a project to build a mobile, pre-engineered pumping and piping system designed to bypass streams impacted by spills of insoluble sinking hazardous materials. The product was to be a completely self-contained, mobile system of submersible pumps, piping, and accessories to provide the basic bypass capability.

SECTION 2

SYSTEM DESIGN

DESIGN PHILOSOPHY AND APPROACH

Underlying the EPA design strategy and specifications was a practical philosophy that acquisition of a reliable and financially viable system would require selection of components principally from commercial items that were stocked and readily available nationwide. This philosophy would also simplify system maintenance and repair. Using the specifications cited below for the system and its components, and the basic philosophy, the design task became one of sorting available products to achieve operational and space compatibility while maintaining maximum operational flexibility at an acceptable cost.

PERFORMANCE SPECIFICATIONS

Major performance specifications established in the contract defined a system that would be:

1. Completely self-contained and capable of independent operation (with liquid fuels supplied separately).

2. Self-propelled (via tractor-trailer) over interstate highways without special permits (two trailers maximum).

3. Able to be fully assembled onsite in 4 hours by five men.

4. Capable of diverting a volume flow rate of 0.35 m^3/s (5,600 gpm) a distance of 0.3 km (1,000 ft), or a lesser flow volume a distance of 0.91 km (3,000 ft.).

5. Continuously operable for 21 days (500 hrs) without dropping below 50% capacity in the event of any single component failure.

6. Mounted for quick removal in case of air shipment of components.

Additional requirements for individual components are detailed below.

Submersible Pumps

1. Fifteen-m (50-ft) total dynamic head (TDH) at design capacity.

2. Manual turndown to 0.009 m^3/s (145 gpm).

3. Fittings for crane hoist lifting and for skidding.

4. Ability to operate 107 m (350 ft) from power source.

5. Electric or hydraulic drive with service line on storage reels.

6. Protected intake to exclude fish and debris.

7. High-level alarm to signal inadequate pumping.

Booster Pumps (Supplied by EPA)

* Two-stage centrifugal booster pumps with 0.09 m^3/s (1,425 gpm) flow volume and 84-m (275 ft) head capacity when used in the single-stage mode (four units).

Piping

1. Lightweight piping in sections weighing 45 kg (100 lb) or less.

2. Quick-connect couplings.

3. Suitability for unprepared ground and for maximum pressure load of booster.

Fittings (Quick Disconnect)

1. Flexible hose at submersible pumps.

2. Valves for control and isolation of components for repairs.

3. A selection of elbows for use where pipeline route is tortuous.

Accessories

1. Pipe dollies to distribute pipe quickly.

2. Tools for maintenance and repair.

3. Floodlighting.

4. Flow rate and flow totalizing meters.

5. Spare parts.

6. Weather covers for equipment (removable).

7. Spoilers to prevent stream bed erosion on return flow.

All these criteria have been met or exceeded in the system delivered.

SECTION 3

COMPONENT SELECTION

An important factor in the selection analysis was compatibility of components with one factor. Because the booster pumps were a given condition of the system (they were provided by the government) this was an appropriate starting point for the analysis. In this section, rationale is given for the component selections made. A listing of those components selected is given in Table 1. Discussion of those components considered and then rejected is limited simply to the listing of such items and the brief comments in Table 2.

BOOSTER PUMPS

The entire operating mobile stream diversion system was built around four each 0.09 m^3/s (1,425 gpm) GP-110-3 petroleum pumps produced by John Reiner & Co. and provided by EPA. Each Reiner pump was powered by a Continental R-602 six-cylinder gasoline engine which had the capacity to deliver the rated flow under an 84-m (275 ft) head. (An 84-m [275 ft] head corresponds to friction loss in 2,160 m [7,090 ft] of 203-mm [8-in.] -diameter pipe). The units were designed to perform in any ambient temperature from -15°C (5° to 122°F) and at altitudes from sea level to 1,500 m (5,000 ft). Because the pumped fluid supplied cooling, and pressure reduced engine speed to idle whenever suction side conditions approached cavitation, priming was a necessity.

SUBMERSIBLE PUMPS

Selection of a practical submersible pump array was based on supplying the demand at the suction side of the four booster pumps. Flexibility and reliability required that one submersible pump be provided to feed each booster pump. (One submersible to feed more than one booster pump would waste booster capacity if the submersible ceased to function.) With one-to-one correspondence, the capacity of each submersible had to exceed the booster demand to maintain suction side flow continuity (0.09 m^3/s [1,425 gpm]) and avoid cavitation. There was also the possibility that debris might choke off part of the flow field. Consequently, it was decided each submersible pump should have a capacity (at the design head) that would exceed the booster flow significantly; e.g., say a 25% greater capacity, and be protected from debris entrainment by expanded metal screens.

TABLE 1. MAJOR COMPONENTS OF MOBILE STREAM DIVERSION SYSTEM

Item	MFR/Model	Specifications
Tractor 2 ea.	Mack Maxidine RL 795L5T	325-HP diesel engine; 2 rear axles, tandem interlock; 10:00 x 20 tires.
Trailer 2 ea.	Fruehauf PF-F2-40	12.2-m (40-ft) trailer w/Budd wheels, 10:00 x 20 tires; 27,000-kg (60,000-lb) capacity.
Submersible Pump 4 ea.	Peabody Barnes 6SEH4004	29.8 kW (40 HP), 3 phase, 460 V, 0.8 PF, 152-mm (6-in.) discharge, 0.12 m^3/s (1,900 gpm), 15-m (50-ft) head, 21-m (70-ft) #2 AWG 4-wire power cable with 600-V, 100-A " Powertite" connector.
Generator 2 ea.	Electro Motion 125 T 6	100 kW continuous duty (125 kW standby), 265/460/575 volt, 3 phase; water-cooled Allis-Chalmers Model 11000 diesel engine; Kurz & Root brushless revolving field 100-kW generator.
Booster Pump 4 ea.	Reiner, GP-110-3 (government-furnished equipment)	Two-stage, 152 mm (6 in.), 0.09 m^3/s (1,425 gpm), 8,370-cm (275-ft) head, gasoline-driven centrifugal pump.
Crane 2 ea.	International Crane Model 309-4	2,700-kg (6,000-lb) capacity 45 kN·m (33,000 ft-lb) electrical hydraulic, self-locking winch; electric 2 radian continuous rotation, 3.4 to 5.1-m lift (11 to 17 ft), 1.2 to 4.2-m reach (4 to 14 ft).

(continued)

TABLE 1 (continued)

Item	MFR/Model	Specifications
Pipe & Hose (approx. 1 km 3,000 ft)	ASC Mainline/Circle Lock (C/L) Agricultural Irrigation Aluminum Pipe w/ Steel fittings	203-mm (8-in.) tubing, 9.1-m (30-ft) length, 1.63-mm (0.064-in.) wall, gaskets, quick connect couplings and lock ring included with each length, 68 pieces (32.1 kg [70 lb] /length); 152-mm (6-in.) tubing, 9.1-m (30-in.) length, 1.47 mm (0.057-in.) wall; gaskets, couplings, etc., 24 pieces (21.7 kg [48 lb] /length) 203-mm (8-in.) tubing, selected length, 1.63-mm)0.064-in.) wall; gaskets, couplings, etc., 18 pieces (various weights, less than 16 kg [35 lb] / length).
	ASC Mainline/Circle Lock Connectors, B.F. Goodrich Nylair 44 Hose and hose patches	33 section flexible hose couplings, 50 m (165 ft) total.
Pipe Fittings	ASC Mainline/Circle Lock Aluminum and Steel	48 pieces: 203-mm (8-in.) elbow, 90°, - 16 each 203-mm (8-in.) valves - 5 each 203- by 152-mm (8- by 6-in.) reducer - 3 each 152- by 203-mm (6- by 8-in.) expander - 5 each 305- by 203-mm (12- by 8-in.) reducer - 3 each 305-mm by 1.5-m (12-in. by 5-ft) long, flanged meter-input - 3 each 305-mm by 0.3-m (1- by 1-ft) long, flanged meter-output - 3 each 152-mm (6-in.) flange to C/L coupler - 5 each 203- by 203- by 305-mm (8- by 8- by 12-in.) Tee - 3 each - with gaskets, couplings and lock rings 152- by 305- by 305-mm (6- by 12- by 12-in.) spoiler tee - 2 each.

(continued)

TABLE 1 (continued)

Item	MFR/Model	Specifications
Winch 1 ea.	Ramsey DC 12-8	2,700-kg (6,000-lb), 12-volt DC portable electric winch, SSI dolly mounted.
Water Meter 2 ea.	McCrometer, Model M C 0500 305-mm (12-in.) meter	0.01 to 0.2 m^3/s range (150 to 3,000 gpm).
Rack/Dolly 2 ea.	Scientific Service, Inc.	2.4 m wide by 5.4 m long by 0.5 m to 0.7 m deep (8 ft by 17 ft, 8 in. by 20 to 28 in.) telescoping pipe rack with 2 pr wheels and drawbar to convert to pipe dolly.
Rack/Dolly 2 ea.	Scientific Service, Inc.	2.4 m wide by 5.4 m long by 0.6 m deep (8 ft by 17 ft, 8 in. by 2 ft) pipe and fitting rack with 2 pr wheels and drawbar to convert to pipe dolly.
Control Center 2 ea.	Scientific Service, Inc.	200-ampere, 600-volt, 3-phase Service Box with: 100-ampere, 480-volt, 3-phase circuit breaker - 2 each; 30-ampere, 277-volt, 1-phase circuit breaker - 3 each; 15-ampere, 120-volt, 1-phase convenience circuits - 2 each; 100-ampere, 480-volt, 3-phase Cutler-Hammer starter relays with remote start-stop and holding relay - 2 each; High/Low water level switches. High water level alarm.
Cable Reels	Hannay C 3034-24-26	207-m (350-ft) storage capacity for #4 AWG 4-wire cable

(continued)

TABLE 1 (continued)

Item	MFR/Model	Specifications
Cable, electric	Cereske Cable #4 AWG 600-volt SO cable	4 each, #4 AWG 4-wire, 86-m (280-ft) power cables with 100-ampere, 600-volt AC Appleton Electric "Powertite" cable connectors.
Floodlight 4 ea.	Sylvania 1500 T 3Q/CL 277 volt	127^{o} horizontal by 98^{o} vertical dispersion; 1,500 watts, 34,400 lumens, 61% efficiency.
Tool Box 1 ea.	12-gauge steel box with SSI-selected tool complement	50-piece selection of maintenance and repair tools, and controllers.

TABLE 2. MAJOR COMPONENT ALTERNATIVES CONSIDERED

Item	MFR/Model	Type	Comments
Tractor	Ford LNT 900	Gasoline	Operating cost too high.
	Ford C 8000	Diesel	Inadequate off-highway
	International F1850	Diesel	First cost too high.
Trailer	Utility Brute	Inside frame	Light weight no cost advantage; first cost too high.
	MAI	Platform	First cost too high.
	Pacific Construction	TX 40 platform	First cost too high.
Submersible Pump	Flygt B2151	Centrifugal	Requires daily lube.
	Flygt C53200	Centrifugal	Restrictive low-side flow.
	Crisafulli High Head	Centrifugal	First cost too high; restrictive low-side flow.
Generator	Onan 115 Owa	Diesel	First cost too high.
	Electro Motion 125HG800	Gasoline	Operating cost too high.
Crane	Hiab 345	Electric/Hydraulic	Not equipped with winch.
	Hiab 550	Electric/Hydraulic	No winch; first cost too high.
	R O Products TC 40 1A	Electric/Hydraulic	First cost too high.
Fittings & Pipe	Fiberglass Resources Corporation	Kwiklok Fiberglass	Pipe too heavy; first cost excessive.

Figure 1 is a performance curve of capacity versus head for the Peabody Barnes centrifugal pump Model 6SEH 4004 selected. Each pump is powered by a 480-volt, 3-phase motor that draws 61 amperes at rated capacity and has a 271-ampere locked rotor startup current. The pump will deliver 0.12 m^3/s (1,900 gpm) at the design total dynamic head (TDH) of 15m (50 ft) or 0.09 m^3/s (1,425 gpm) (the booster flow) at 22-m (72.5-ft) head. The 22-m head corresponds to the friction loss in 573 m (1,900 ft) of 203-mm (8-in.) pipe at 0.09 m^3/s (1,425 gpm). Thus, over level ground, each submersible pump can deliver 0.09 m^3/s (1,425 gpm) at a distance of nearly 0.6 kilometers (2,000 ft) provided the output from each pump flows through its own 203-mm (8-in.) pipe.

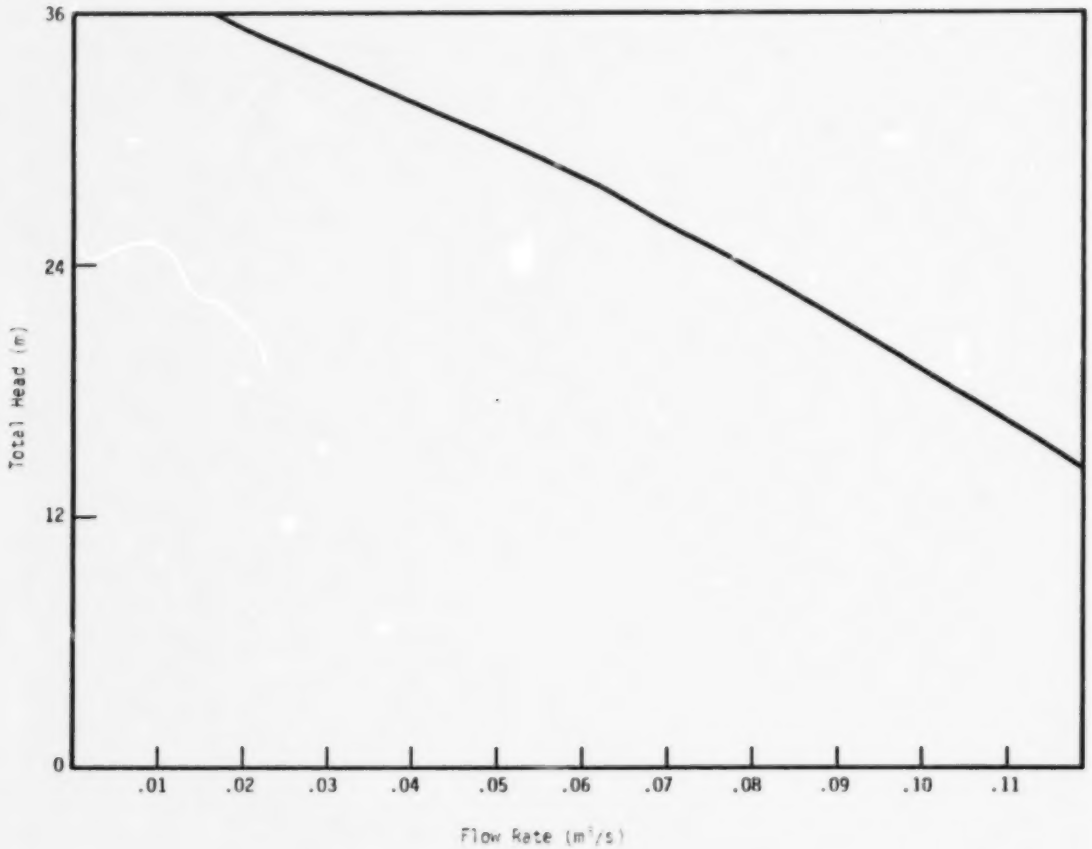


Figure 1. Submersible pump performance curve.

At the lower limit, the pipe flow can be turned down to 900$_3$ cm^3/s (14 gpm) without overheating the pump motor. To ensure a 900-cm^3/s (14-gpm) cooling flow through each submersible pump, a 6-mm (0.236-in.) hole has been drilled in the flanged fitting attached.

Submersible Pump Cables and Cable Storage Reels

Power cable requirements for the submersible pumps were determined by the continuous duty demand at the pumps' maximum operating capacity, by the voltage drop that could be tolerated in 107 m (350 ft) of cable, and by safety requirements. These requirements were 61 amperes, something less than 20 volts, and an internally grounded (4-wire) power cable system, respectively.

National Electric Code specifies 70 amperes as allowable current carrying capacity of #4 AWG 4-wire cable with utility-grade insulation (such as RW, T, TW, UF, S, SO) in 3-phase continuous service at ambient temperatures of 30°C (86°F). With increased ambient temperature, the allowable continuous service current-carrying capacity of a given conductor must be reduced. This will become 64 amperes at 35°C (95°F), 57 amperes at 40°C (104°F), and 50 amperes at 45°C (113°F) for the specific cable cited. An ambient temperature condition outdoors which equals or exceeds the latter temperature will be extremely unusual and will occur only in the heat of the day. It is a simple matter to compensate, should this occur, simply by turning flow volume down slightly during periods of high ambient temperatures above 35°C (95°F). Moreover, the voltage drop in 107 m (350 ft) of this cable drawing 61 amperes in 3-phase service is less than 10 volts. Consequently, a #4 AWG 4-wire SO cable is adequate for field service. (SO is a utility-grade, waterproof, oil- and acid-resistant insulation for outdoor use).

The Peabody Barnes pumps selected came equipped with 21 m (70 ft) of #2 AWG 4-wire SU cable rated at 66 amperes at 45°C (114°F). (SU is equivalent to SO with the additional property of abrasive resistance.) To meet the total requirements for 107 m (350 ft) of cable per pump unit, an additional 86 m (280 ft) of #4 AWG 4-wire SO cable was provided for each pump and mounted on Appleton "Powertite" 100-ampere internally grounded connector (see Figure 2A, C, D) that served as a safety disconnect as required by the National Electric Code.

For easy access onsite, the pump service lines were required to be stored on reels (Item 5 of the performance specifications for submersible pumps). For this purpose, four Hannay Reels, Model C-3034-24-26 were selected. They had hand cranks for rewinding and a capacity of 100 m (330 ft) of #4 AWG 4-wire SO cable. Each of these reels was used to store 86 m (280 ft) of service cable extensions. Two cable reels were mounted on a dolly designed to allow the cable to be paid out directly off the storage reel to minimize dragging.

Figure 2. Submersible pump auxiliary features.

Float Switches

Remote automatic switches to start and stop the submersible pumps and to warn of high water conditions were specified as part of the operating system. To comply with requirements, three mercury switches (each enclosed in a float) were provided. Float orientation, controlled by water level, actuated them. Two of the switches controlled one of the pumps on each unit ("on" at low water in the catch basin and "off" at high water) and the third switch sounded an alarm if the water rose above the high-water pump switch control (for example, in case of a pump failure). The pump control switches were linked to the pump starter relay via a 107-m (350 ft) #14 AWG 3-wire SO cable, and the high-water alarm switch was linked to a claxon via a 107-m (350-ft) #18 AWG 2-wire SO cable. The latter was connected to the 24-volt DC battery supply on the generator and the former was connected to the 480-volt AC output.

Mounting of the float switches is depicted in the sequence of photographs in Figure 2. Figure 2 shows a pump pinned in place on the deck of a trailer (A); one of the multiple crossarms being inserted into the square tubing that is part of the pump skid (B); the pair of float switches that turn the pump on and off remotely (C); and a second position for the float switch that turns the pump on at high water (D).

GENERATORS

Selection of the generators was based on the power demands of the pumps and on the damands for the floodlighting and convenience circuits used for battery chargers, power tools, comfort heaters, etc. Continuous duty demands were set by the submersible pump requirements, the remaining requirements could be covered by standby capability of a generator. The continuous duty demands on the generator were 97 kW, to power the submersible pumps at their rated capacity. The remaining demand was likely to be less than 10 kW so that a standby capacity of 110 kW would ordinarily by sufficent. However, the largest single power requirement was the startup load of the submersible pumps. Careful analysis of this requirement indicated that a 125 kW standby capacity would be sufficient to start both submersible pumps, provided the two pumps were started sequentially.

Cost benefit analysis indicated that a diesel generator would be preferable. This preference was based on the trade-off between the incremental first cost of the diesel generator over a gasoline generator of comparable size and the differential fuel costs for gasoline over diesel fuel. The trade-off favored diesel after 1,000 hr of operation. Hence, each unit was equipped with an Electro-Motion 125 T6 Diesel Generator assembled from an Allis Chambers turbocharged Model 11000 water-cooled diesel engine and a Kurz & Root reconnectable brushless revolving field four-pole generator.

Control Center

The generator was equipped with a built-in main circuit breaker rated at 600 volts, 200 amperes, and with an adjustable temporary overload delay. National Electric Code required that each power take-off circuit be protected against continuous overload and that such protection be mounted in a NEMA 3 service box if it were outdoors. A simple 600-volt, 200 ampere "fusible and motor starter panelboard" from Cutler-Hammer was selected (Figure 3) for this purpose. In it were installed two 480-volt, 100-ampere, 3-phase breakers to service the two submersible pumps, and three 277-volt, 20-ampere, 1-phase breakers to service each of the two 277-volt floodlights and a 277-volt/120-volt 3-kW transformer providing two 120-volt convenience outlets for power tools, trouble lights, heaters, etc. Each of the three 277-volt breakers provided service from a different leg of the generator, to distribute the load. The service panelboard also provided the "Lockout" capability specified in the National Electric Code as a safety requirement in

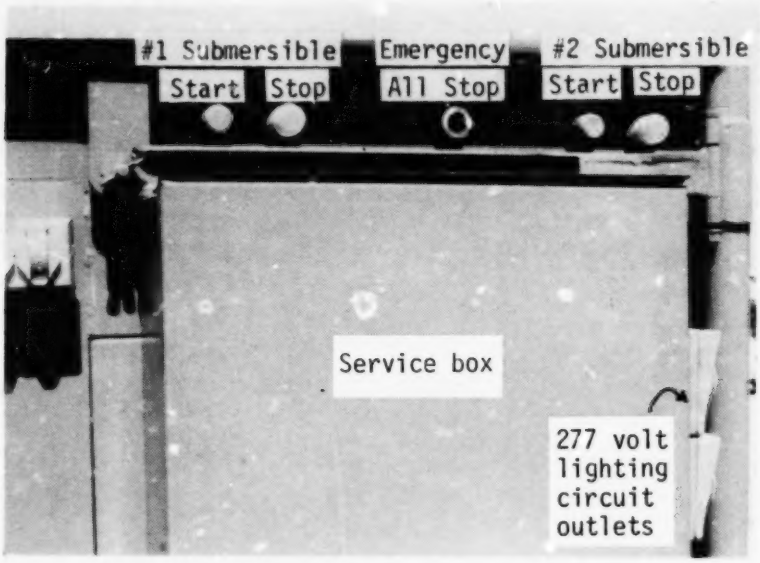
Figure 3. NEMA 3 service box.

cases where the service panel would not be visible from the motor being serviced. (A complementary Code safety feature required a valid disconnect within sight of each motor. The "Powertite" cable connectors that terminated each cable were selected to provide this disconnect feature.) The panelboard served principally as a distribution service box that divided the power output of the generator into appropriate voltages to service the various MSDS components and protected each of these and the generator with a circuit breaker. As it was not likely that access to the service box would be needed often, it was located in front of the generator control panel, but hinged to the protective pipe-framework so it could be swung clear to gain access to the generator control center (Figure 4), when necessary.

The generator control center was mounted inside the weather housing that covered the generator. Also under this housing were the starter relays needed to activate and protect the submersible pumps. Each starter relay was equipped with a fusible link (matched to the continuous duty current draw) to protect the pump in case of an overload, but which would pass the temporary "locked-rotor" current required for startup. A remote-start circuit was also provided, and a holding relay was supplied to override short-term signal changes (such as would occur if a float-actuated switch were to ride up and over a wave). To assure reliability, the starter relays were enclosed separately to protect them from damange in a dusty operating environment. Cutler-Hammer relays were 480-volt, 100 ampere, 3-phase units mounted in NEMA 3R (dustproof) enclosures. For each leg of the 3-phase circuit, 61.3 to 64.9-ampere heater coils (fusible links) were used to protect the submersible pump motors. Each pump was wired for local start and stop at the control center and one pump on each trailer was operated from remote start and stop via the float switches at the submersible pump. (The rationale for only one remotely controlled pump per unit was that it would be adequate to preclude either overflowing or draining of the pump catch-basin whenever two pumps were used, or else one pump would be sufficient.)

The generator control center was equipped with low oil pressure, high water temperature, overspread, and overcrank automatic shutdown and audible (siren) alarm circuits. These were augumented by a separate high water audible (claxon) alarm. The generator-fuel high/low-level alarm was connected on the same panel (and claxon). All these circuits were equipped with "acknowledge" switches to deactivate the alarms, in particular where the passage of time (high water-temperature) or an action (add oil) would be required before reset was possible. The alarms were selected to operate either by 12-volt DC or by 24-volt DC (rather than generator AC) so that shutdown notification would be ensured.

The generator control center included voltmeter, ammeter, frequency meter, running-time meter, oil pressure and water temperature gauges, and field (circuit) breaker. A phase selector switch enabled voltage and current in each leg to be measured so that lighting and convenience circuits could be balanced, or continuous-duty overload conditions determined. An "emergency stop" switch was mounted prominently on the weather cover (above the service submersible pumps) to provide the safety of a total shutdown (see Figure 4) capability.



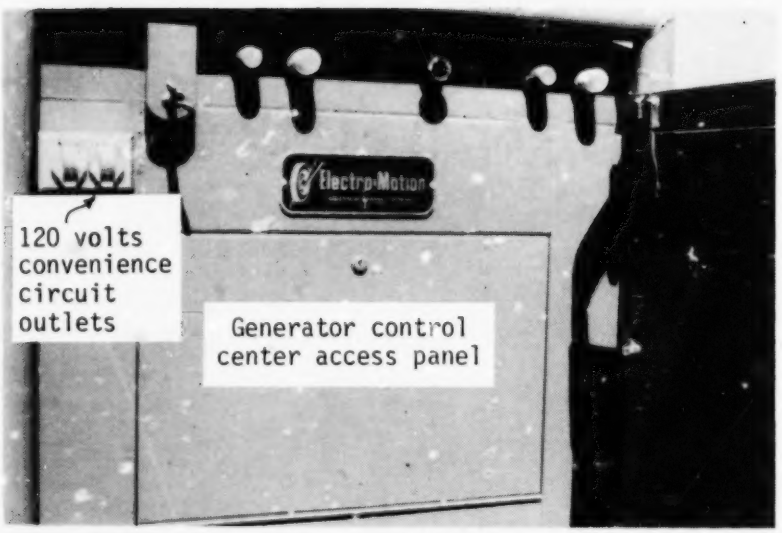


Figure 4. Generator circuit and control center features.

PIPES, HOSES, AND FITTINGS

A practical system of piping and fittings that could be rapidly distributed and assembled at any site had to satisfy many requirements. Pipe needed to be lightweight, provided in manageable sections with strength sufficient to withstand the 84-meter (275 ft) pressure head, be rigid enough to take the weight when laid over unprepared ground, be flexible at pump connections, have a sufficient complement of valves to enable pump components to be isolated for repairs without necessitating equipment shutdown, and be supplied with a complement of elbows to enable direction changes to be made in the pipeline where needed. Finally, friction loss in the pipe could not exceed available pumping head for the volume flow rate and pipe length required and all had to be packaged to fit together compactly for transport to a site.

Fortunately, because many of these requirements applied also to agricultureal irrigation systems, a good many of the desired qualities for the MSDS pipe were available in a commercial product. Thus, it was necessary only to select a complement of irrigation pipe size(s) and lengths to meet the requirements for rigidity, pressure rating, limited friction loss, acceptable weight per section, total line length, efficient storage, and distribution and assembly and valves and fittings sufficient for completing assembly in the field. A fair number of tradeoffs were involved, nevertheless, Moreover, the industry discouraged the notion of "nesting" any small-diameter pipe inside larger pipe to save space. Two reasons were given: sliding one pipe into or out of another had been found to wear pipe out physically, and the process was reported to become tiring very quickly.

Commensurate with all these demands, it was concluded that the 203-mm (8-in.) pipe was the largest practical diameter, as determined by the pressure head requirements. At the upper range of volume flow rates desired, the next smaller size of irrigation pipe readily available (152 mm [6 in.]) was adequate but there would be about four times the head loss per unit length of smaller pipe. System potential for delivery of 0.09 m^3/s (1,425 gpm) could be enhanced over longer distances by the use of 203-mm (8-in.) pipe (that is, the range would be four times that with 152-mm (6-in.) pipe). In anticipation that incidents could occur that would require very rapid response to supply water (for example, nuclear water coolant loss; bypassing a contaminated community water supply) where a long run of pipeline might be an important factor selection of pipe and fittings was weighted heavily in favor of the 203-mm (8-in.) diameter.

With regard to fittings, rigid elbows were acquired for the pump and metering hookup and flexible elbows for every three lengths of pipe in the line. The flexible elbows were made up of short (0.7 and 1.5-m [2.3 and 5-ft]) lengths of B.F. Goodrich Nylair 4" hose, clamped to quick-connect couplings by means of stainless steel bands applied with a Band-it tool. The couplings used were of a standard agricultural irrigation coupler-pair, each welded to a section of standard Goodrich serrated steel hose-patch which ensured a good grip on the hose. With these flexible elbows and the additional flexibility provided at each pipe joint by virture of the unique gasketing, a pipeline could be constructed through a forest, if necessary.

Moreover, the flexible joints would also preclude transmission to the pump mounting of thermal stresses developed as temperatures in the metal pipe changed.

Flexibility was provided at the submersible pump discharge by means of 3-m (10 ft) lengths of 152-mm (6-in.) hose and couplings. A 152- by 203-mm (6- by 8-in.) expander-fitting enabled each 152-mm (6-in.) pump hose to be connected to the 203-mm (8-in.) mainline pipe. Where this line was connected to the booster pumps, a yoke, or manifold, was bolted on each intake (and exhaust) to provide a quick-connect 203-mm (8-in.) coupling that joined the pipeline to the two 152-mm (6-in.) flanged fittings on the suction and discharge lines of each pump.

One 203-mm (8-in.) valve on the discharge side of each booster pump controlled the flow volume manually, when desired, and isolated a pump unit for repair when necessary. The potential for cavitation and/or bearing damage precluded use of flow valves on the intake (or suction) side of the booster pumps; hence, four valves (and a spare) constituted an adequate supply.

A spoiler fitting supplied with each unit prevented stream erosion at the downstream return point. The spoiler comprised a 305-mm (12-in.) section of pipe, open at both ends, welded to a centrally connected 152-mm (6-in.) quick-connect coupler. The spoiler reduced pipe flow at discharge to 2.5 to 3 km/hr (1.6 to 1.9 mi/hr), so that a plastic sheet spread over a 5- by 5-m (16- by 16-ft) section of stream bed would preclude erosion.

Distrubution and assembly of the pipe and fittings was analyzed in detail to determine requirements imposed on packaging. Estimates indicated that, to be able to distribute and assemble the entire system and have it operating onstream in 4 hours with the five-man crew, the distribution and assembly of the entire pipe complement could be allocated no more than 2 to 3 hours. Consequently, an evaluation of pipe distribution and assembly options was conducted.

Pipe Racks and Dollies

A simple evaluation of the total distance covered in travel along the pipeline was made assuming distribution of 914 m (3,000 ft) of 9.14-m (30-ft) lengths of 152-mm (6 in.) pipe, one at a time, by hand. (This pipe length was selected to be manageable by one person, as each unit weighed under 22.7 kg [50 lb]).

Each time a crew member delivered a length of pipe to the end of the pipeline, the total line length would be traversed twice (round trip). Thus, total travel required to deliver 100 lengths was calculated as:

$$L = [(1 + 100)/2] \times 100 \times 9.14 - [100 \times (9.14/2)] \times 2 = 91.4 \text{ km}$$

or an average of 18.3 km (12 mi) per crew member (wi a 22.7-kg (50-lb) load

half the time). Clearly, it would take over 4 hours under ideal conditions for the five-man crew to do more than deliver even this small size pipe along the pipeline.

A calculation similar to the one above showed that the minimum distance travelled with a 3-pipe dolly would be 30.5 km (19 mi), or 61 man kilometers (two-man operation). Divided among the five-man crew, the task would average 12.2 km (7.6 mi) per crew member (though without the burden and cumbersome task of handcarrying). Nevertheless, it was estimated that just delivering the pipe along the line would require 2 to 3 hours, so that a larger dolly or a larger crew would be required. The larger dolly was considered practical, provided the idea was kept in mind that it would be inefficient to transfer pipe at the site; that is, the pipe should arrive at the site already loaded on the dolly.

The combination rack and dolly that appeared mandotory to meet the time specifications was not available as a commercial item. Adjustable rack and dolly units of maximum practical size had to be designed for pipe and for pipe and fittings to carry out the pipe distribution operation. (Details of the system are given in Figures 5 and 6.)

With this system, the pipe was readily unloaded while still in the racks, and the racks were converted to dollies in 15 minutes. Five men could lay 1 km (3,280 ft) of pipe in 1-1/2 to 2 hours over reasonable terrain, and with the dolly hitched to the tractor, two men could lay 1 km (3,280 ft) of pipe in 5 hours (and in an emergency, one man alone could lay pipe this way).

Metering

Once the pipe and pumps were in place and operating, the pumping system could be made to operate more efficiently by adjusting it to pump at a nearly continuous flow rate, rather than leaving it to cycle off and on according to High/Low float switches. The current could be less at lower flow rates, the generator would not have to work as hard, and a corresponding lower fuel consumption, operating cost, and air pollution would result.

Metering provided an effective means for empirical determination of an appropriate flow rate to match stream flow. With High/Low switches a fixed distance apart, one needed only to time the periods between activation of the switches from high to low (t_{hl}) and from low to high (t_{lh}) and to record the pump flow volume, q_p, during the pump "on" cycle, to define the stream volume flow, q_s. That flow volume could be calculated as:

$$q_s = q_p \times \Delta t_{hl} \quad (\Delta t_{lh} - \Delta t_{hl})$$

Clearly, with the stream flow, q_s, defined, one could simply close down the valve (on the pump discharge) until the new flow registered on the meter. Thereafter, little cycling would occur because the pump rate would equal the stream flow rate. Though a perfect match would be unlikely, the pumping period would be extremely long, the off period relatively short, and the

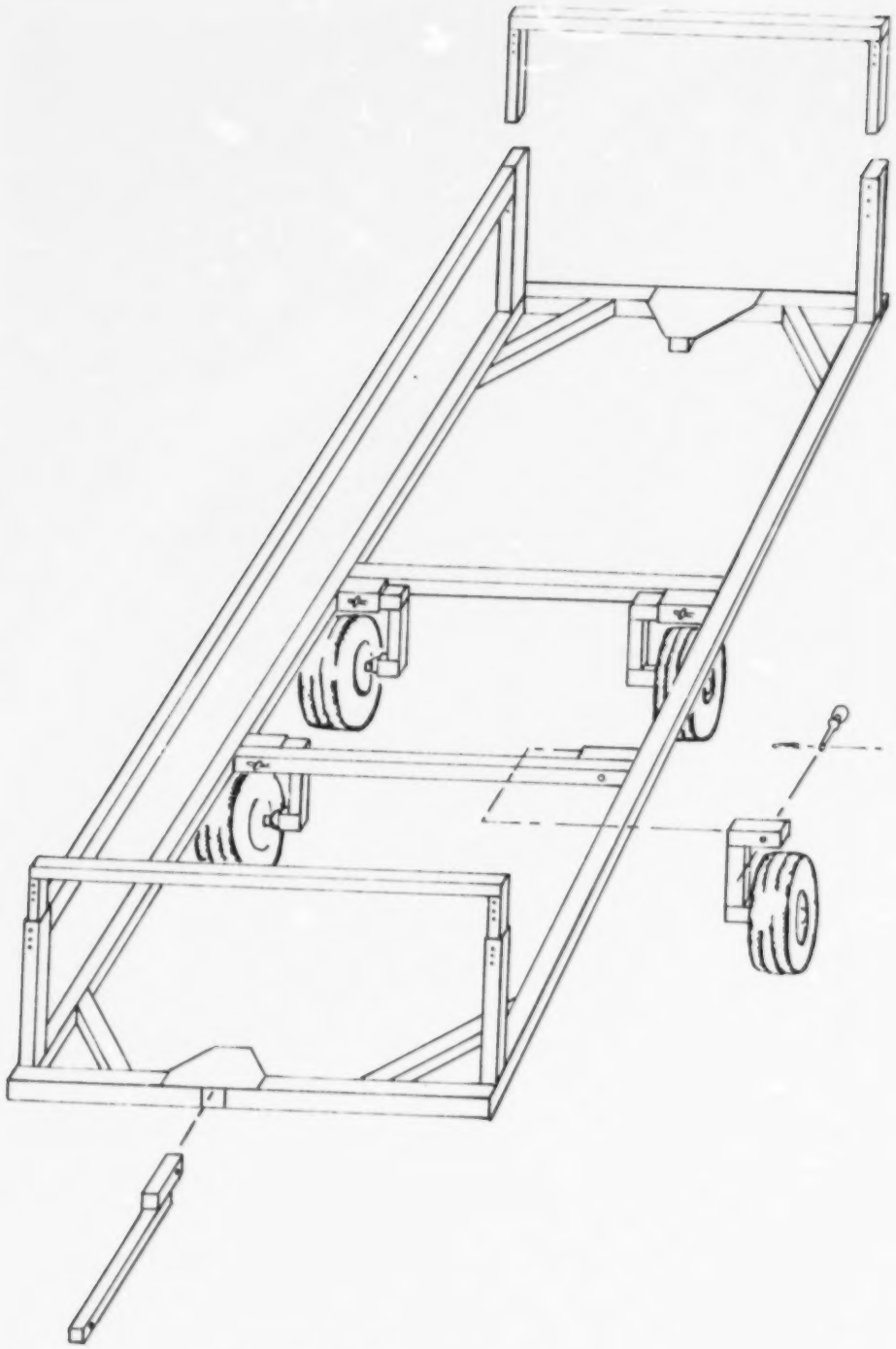


Figure 5. Pipe rack/dolly.

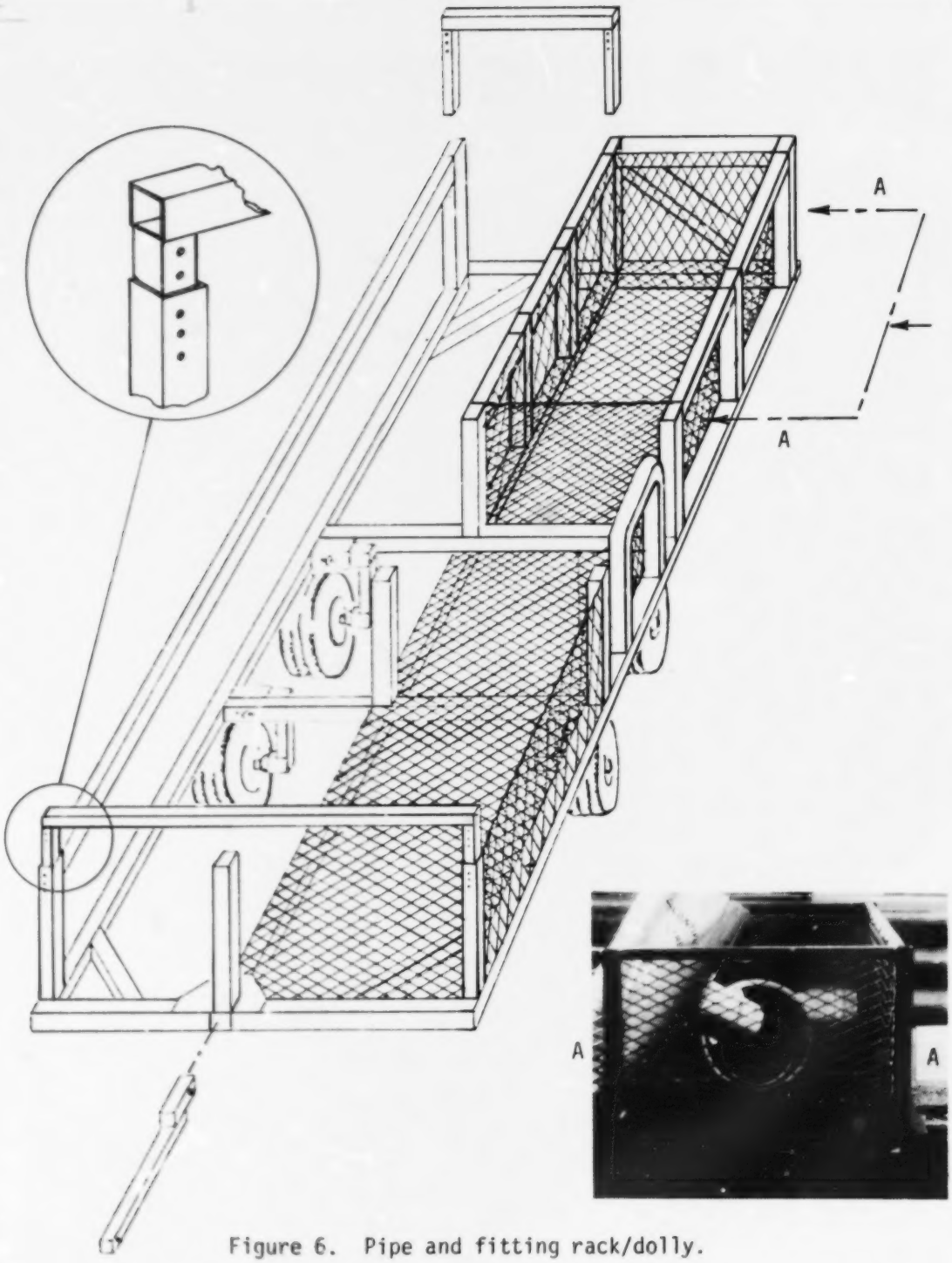


Figure 6. Pipe and fitting rack/dolly.

operational efficiency near a maximum.

A "McCrometer MC 0500-12 inch" flowmeter and totalizer was furnished for each unit. This was the smallest size meter capable of monitoring a flow volume of 0.18 M^3/s continuously. The unit was purchased with a special heavy-duty bearing, required to enable the meter to operate at this flow volume continuously. At the low flow rate extreme, the meter could read down to 9 l/s (145 gpm). (The meter, shown in Figure 7, is graduated in hundreds of gallons per minute. An electronic head can be purchased for remote readout, control, or warning signal.)

Because the meter was bulky and heavy, and required a 1.5-m (5-ft) straight section of 305-mm (12-in.) steel pipe upstream and 0.3 m (1 ft) of 305-mm (12-in.) steel pipe downstream (steel was required in this size to meet internal pressure requirements), this entire section of 305-mm (12-in.) pipe, with meter, was mounted under the trailer, protected in the lee of the landing gear from major road hazards.

CRANE

The maximum load imposed by items that would be unloaded onsite was computed as something less than 1,700 kg (3,800 lb) (the pipe and fitting rack) with a lever arm of less than 2.4 m (8 ft) required. Maximum moment, therefore, would be under 45 kN·m (33,000 ft-lb). A crane with a cable hoist was necessary in order to meet the specification for direct drops of submersibles 15 m (50 ft) from a bridge into the stream below, should that be required.

Figure 7. Metered flow through one unit. (Note this flow rate is for two submersibles through 273 m (900 ft) of 203-mm (8-in.) pipe.)

The crane selected was a Model 309-4, manufactured by International Crane Corporation, which had 22 m (70 ft) of cable, a 45 kN m (33,000 ft-lb) maximum moment, and a 2,700 kg (6,000 lb) maximum load capacity. This crane provided 360° continuous rotation capability and a telescoping boom that was hydraulically operated (112 kg/cm^2 [1,600 lb/in^2]) and electrically powered (12 volt DC). A 12-volt DC system was selected over a 24-volt system so that in an emergency the crane could be powered by the tractor's heavy-duty 12-volt system using a set of jumpers specially made of 4/0 welding cable and provided with each unit.

TRANSPORTATION SYSTEM

An analysis of the deck space requirements for the major components (booster pumps, generators, submersible pumps, crane, pipe- with pipe stacked to maximum practical height) indicated a total load area almost equal to the deck area of the largest trailer allowable on interstate highways. When area was added to account for the spacing required between components to ensure adequate cooling of engines, working space for personnel to unload components, and clearance space needed to operate one on-board crane, the total deck area required became considerably greater than that available on a single trailer. Because there appeared to be no alternative to a two-trailer system, added flexibility, reliability, and practicality were provided by designing two totally independent units. With this kind of redundancy, should one unit get delayed or lost in an accident, it would not affect the operation of the other unit. Moreover, on spills into small streams the second unit could become standby and be dispatched elsewhere, should the situation warrant.

Perhaps the greatest benefit of the two-unit system was that it enabled a design approach to be used that would result in units that could have access to state as well as interstate highways without special permit. Information on state vehicle code weight and dimension limits for each state was obtained from the California Trucking Association. These data defined certain constraints on the MSDS transport system if it were to have access to all state and interstate highways without restriction. The most stringent conditions of allowable semi-tractor height and trailer dimensions and weights were used to establish the following criteria for design of the MSDS transport system:

Maximum height above roadway:	3.81 m (12.5 ft)
Maximum width:	2.44 m (8 ft)
Trailer length:	12.19 m (40 ft)
Total length:	16.76 m (55 ft)
Single axle load limit:	8,164 kg (18,000 lb)
Tandem axle:	11,794 kg (26,000 lb)
GVW (5 axle):	26,762 kg (59,000 lb)

Trailers

The array of components shown in Figure 8 favored a trailer with inside frame to provide support for the concentrated loads along the centerline. A steel frame trailer was selected over aluminum because the higher cost of aluminum could only be offset by the payload weight saved on a high regular annual mileage hauling schedule, which would be inappropriate to the intended use. The steel frame also enabled a steel welded crane mount to be used. A PF-F2-40 Fruehauf steel platform trailer with 12.19 m (40 ft) bed-length was selected because it was a stock item and had the lowest bid price of acceptable trailers. Moreover, its 27,000-kg (60,000 lb) capacity was more than adequate for the estimated 16,000-kg (35,000-lb) payload (20,500 kg [45,000 lb] total load) and the excess capacity provided the additional flexibility of last-minute relocation of load.

Tractors

The single axle load limit in the state vehicle codes imposed another important constraint. To meet this load requirement, a choice had to be made among the following: a special wheel and tire size; dual wheels on one axle; or tandem axles. The policy of rejecting special purchase items eliminated the first option. Though dual wheels were acceptable, the tandem axle would enable specification of a tandem interlock system that would provide four drive wheels. Becuase off-highway use was another specification, a tandem rear axle tractor was selected.

LIGHTING SYSTEM

The design criteria used for the lighting system were based upon typical lighting levels used in auditorium, theatre, and hotel lobbies as 200 to 250 lm/m^2 (19 to 23 fc) . (Such lighting levels would be slightly below the requirement for general classroom and reading activity.) Selection was made from floodlights that operated at 277 volts and had an output per unit area compatible with the design requirement and commensurate with illumination geometry. At a height of 3.7 m (12 ft) off the ground, a floodlight with an 127^{o} dispersion in one direction and 98^{o} in the other would deliver light over an area approximately 15 x 8 m (50 x 25 ft). Each trailer was provided with two floodlights. These floodlights were rated at 1,500 watts and produced 22,000 lm each, about 180 lm/m^2 (17 fc)*.

One 107 m (350 ft) #14 AWG 3-wire SO power cable, terminated at each with a Woodhead Safety Yellow water-resistant connector, was provided with each trailer unit for operating one floodlight at a range equivalent to the maximum distance at which the submersible pumps could be operated from the trailer.

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* Baumeister, T., Anallone, E. A., and Baumeister, T. III.; "Mark's Standard Handbook for Mechanical Engineers," McGraw-Hill, NY., NY., p. 12-126, (1978).

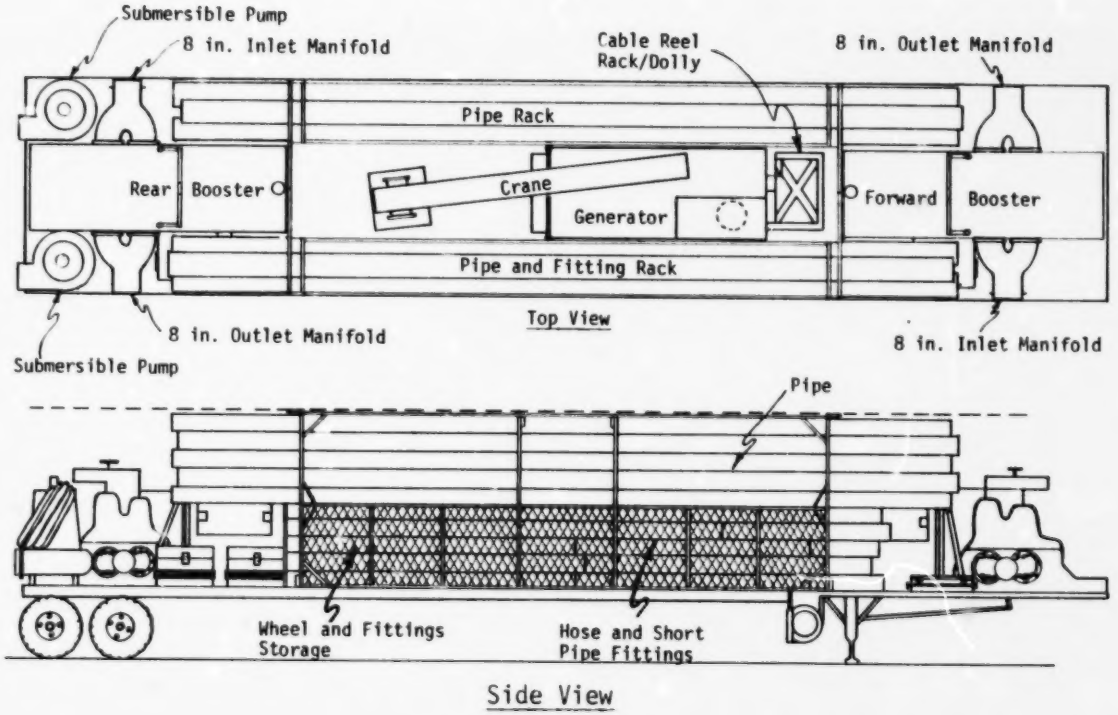


Figure 8. Layout of components aboard trailer.

SECTION 4

TRAILER LAYOUT AND SITE PREPARATION

The general arrangement of the Table 1 components on a unit is shown in Figure 8. Figure 9 is a typical elevation view with the pipe and fitting rack removed. Noted in Figure 9 is the reach of the crane and its main body clearance requirements. For most response operations, only the pipe, submersible pumps, and power cables need be unloaded, appropriately distributed, and assembled. Because time is of the essence, each of the racks converts to a wheeled dolly - the dolly wheels are stored in the expanded metal section of the pipe and fitting rack (see Figure 8) - to simplify and speed setup of the system. Figures 10 through 13 depict the unloading sequence for the pipe and fitting rack and its conversion to a dolly. Figures 5 and 6 show features of the pipe and the pipe fitting rack. An isometric view of a typical wheel assembly and mode of attachment is illustrated in Figure 5. Drawbar pins are used to secure those major system components to the trailer which will be unloaded onsite (in order to facilitate quick release on arrival and/or when air trans-shipment is necessary), and to assemble various dollies used to distribute items onsite.

The wheel assemblies used to convert the pipe, and pipe and fitting racks to dollies to distribute pipe are also used again to deliver the submersible pumps and distribute power cables. Figures 14A and 14B are photographs of a submersible pump dolly and a cable-reel dolly, respectively. Both dollies can be moved by hand over smooth and nearly flat terrain, or they can be hitched to one of the tractors. Should the region between the off-highway staging point and the stream be inaccessible by tractor, a portable winch with 2,700 kg (6,000 lb) capacity is available. This winch and its battery can be easily carried by two men, or fitted with wheels (see Figure 15) and dragged to a vantage point from which to winch a submersible pump into place (using successive staging points for the winch by tying it to a tree, or to a ground anchor). Such a winching procedure might be required for operating in a woods, over steep or rolling terrain, or down an embankment. Finally, should access to a stream be precluded except by a vertical drop, for example, off a bridge the trailer can be parked on the bridge, the crane boom extended 4 m (14 ft), and the submersible pumps lowered 15 m (50 ft), by rerigging the crane cable to operate with a single winch line. (If it is necessary to operate the pumps and remain within the single winch-line load-limit. However, with two winch lines, both submersible pumps can be suspended by one crane if limited to a reach of 3.3 m (10 ft) and a drop of 10 m (33 ft).)

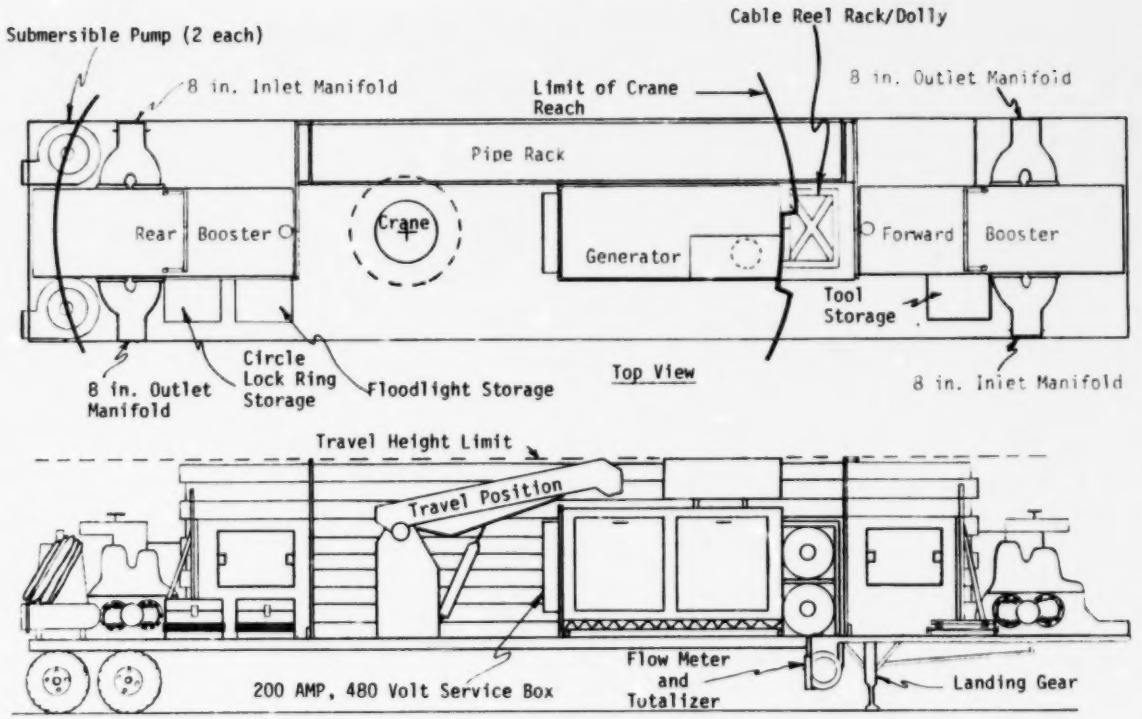


Figure 9. Layout of components with pipe and fitting rack removed.

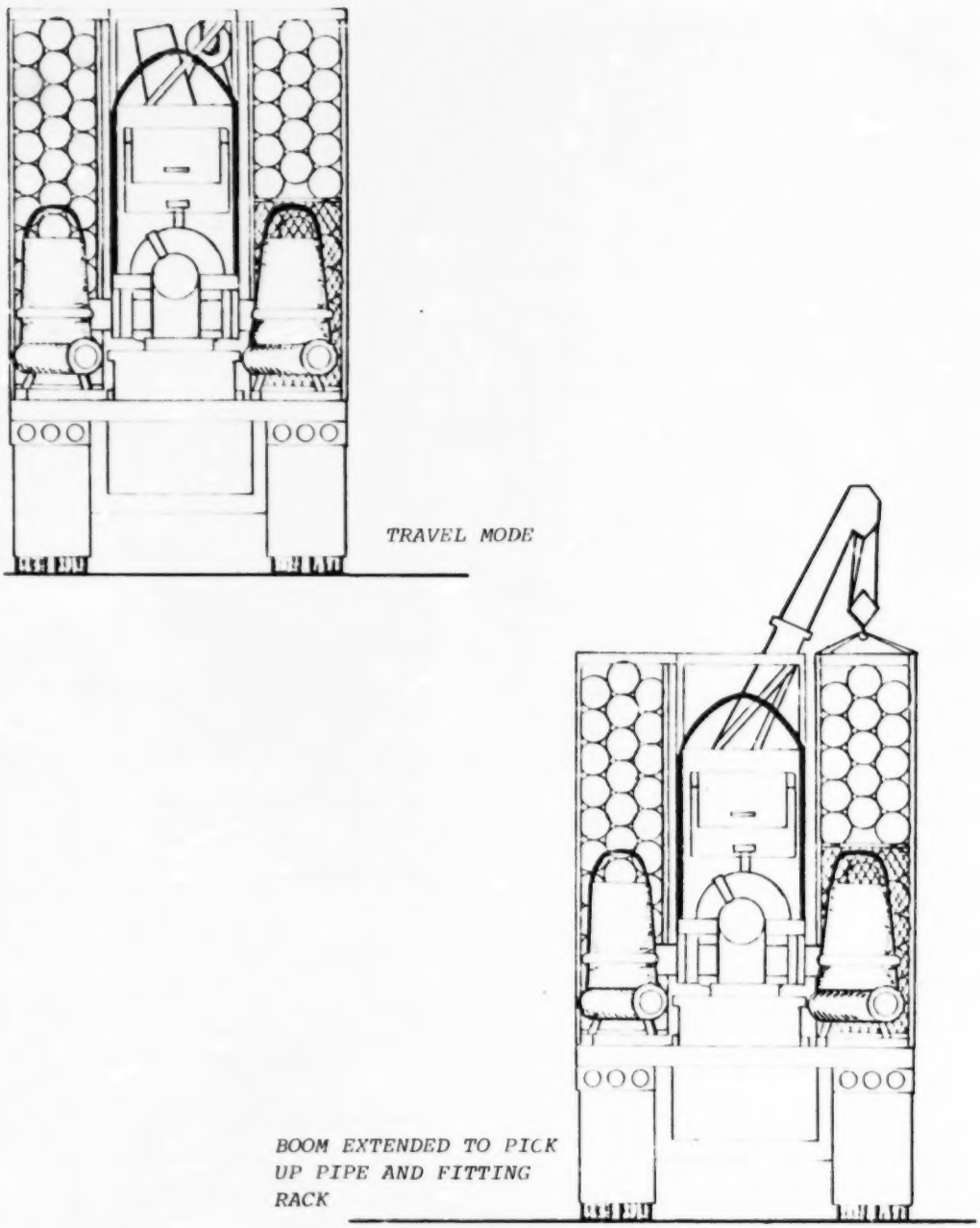


Figure 10. Rear view of trailer with components aboard.

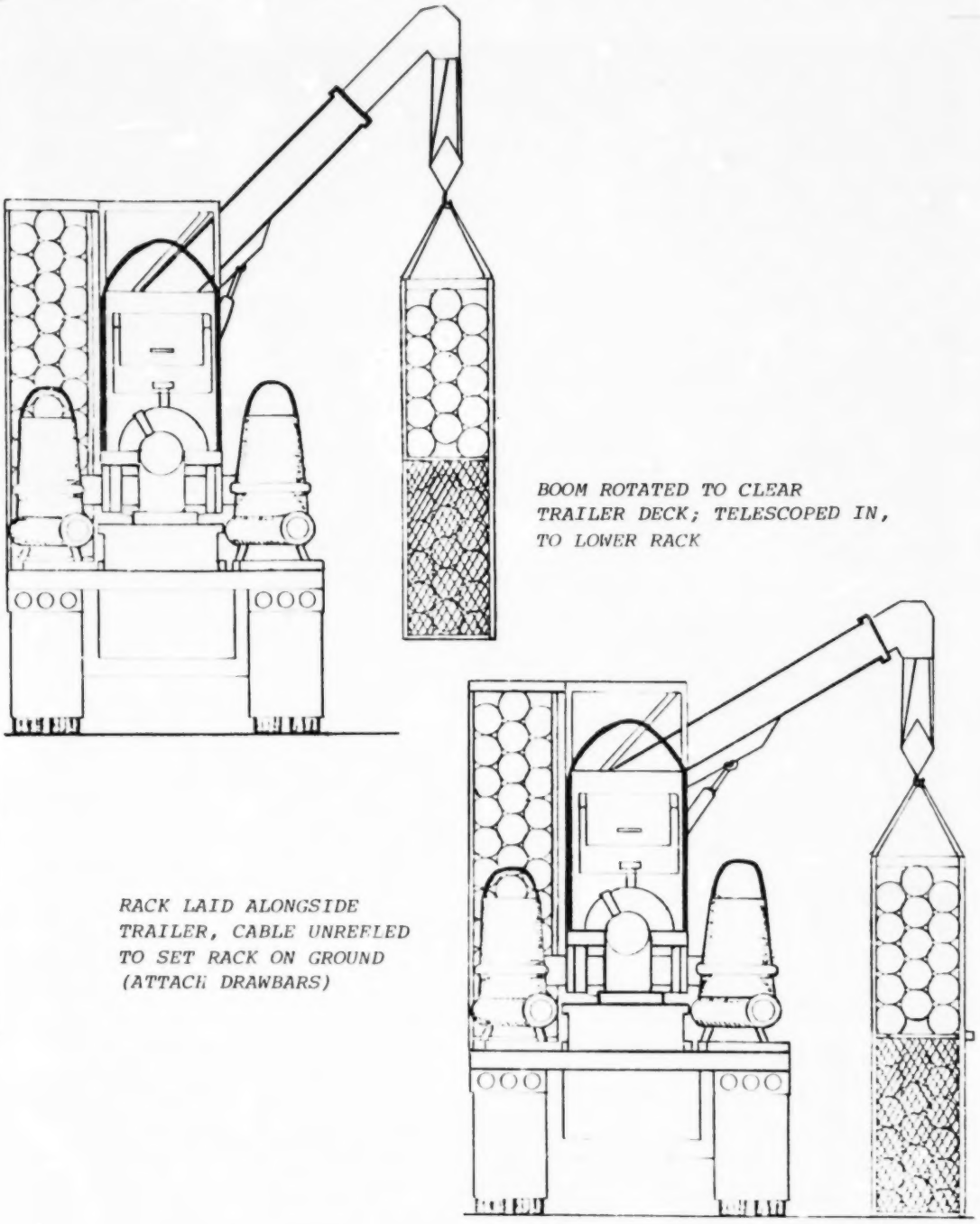
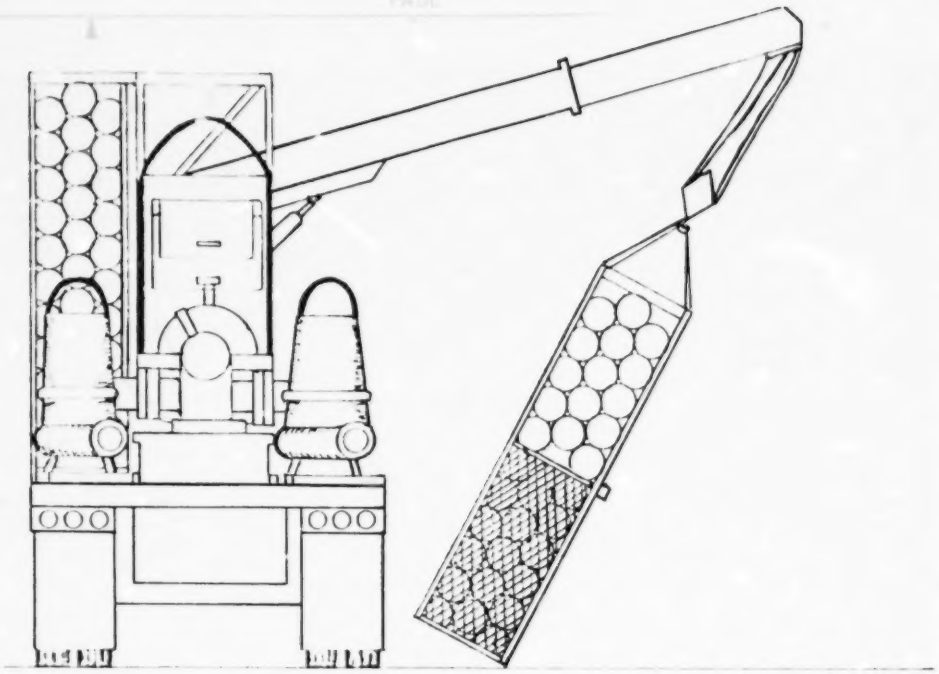
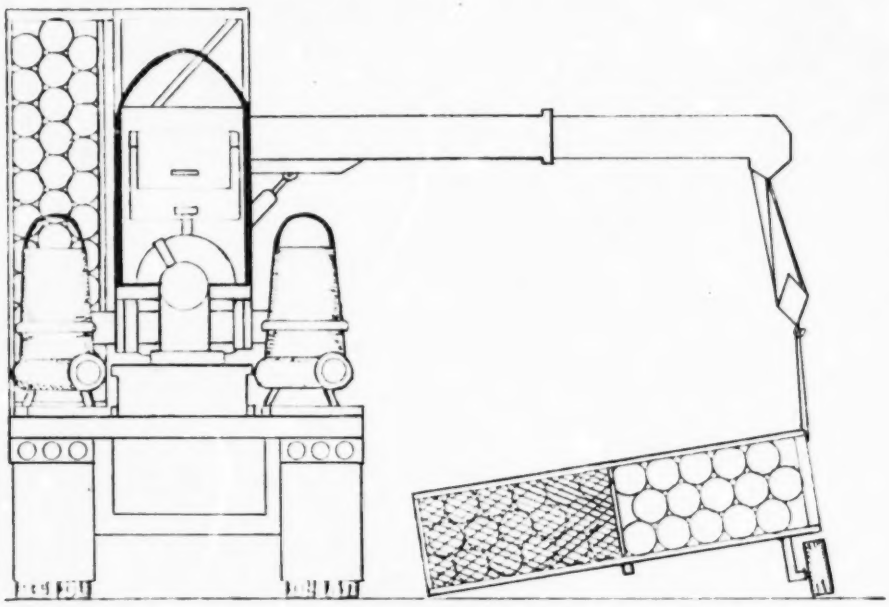


Figure 11. Pipe and fitting rack unloading.

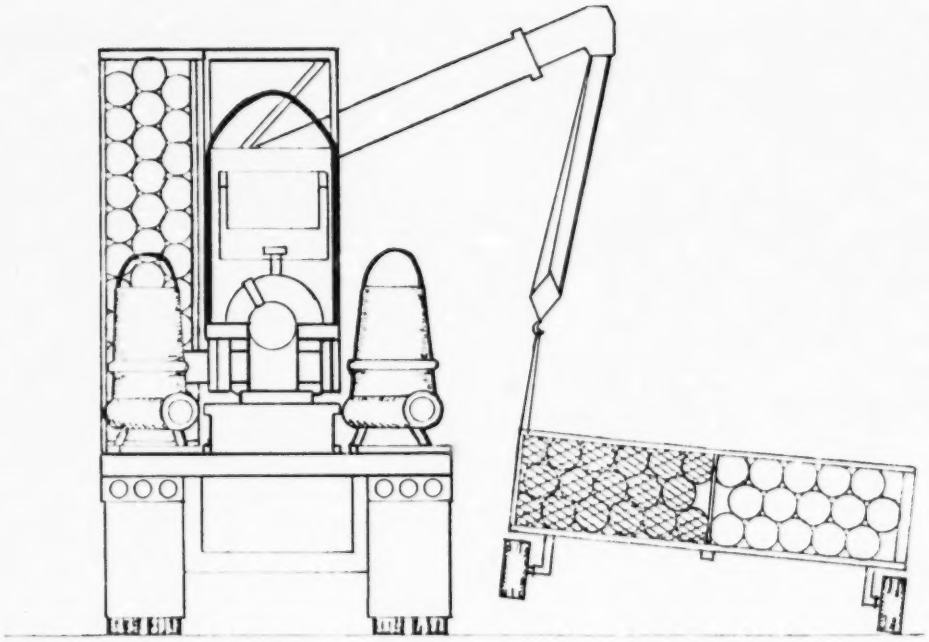


BOOM EXTENDED, ALTERNATED WITH DOWN CABLE, TO ROTATE RACK NINETY DEGREES



AFTER TURNOVER, BOOM LOWERED, WHEELS ATTACHED, AND TOUCHED TO GROUND

Figure 12. Pipe and fitting rack rotation and wheel assembly.



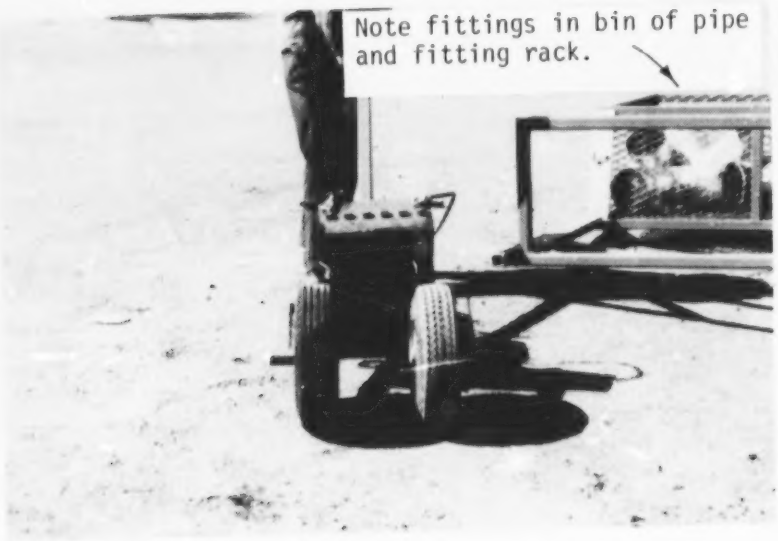
BOOM RETRACTED AND HOOKED TO OPPOSITE SIDE, RACK RAISED, AND SECOND PAIR OF WHEELS ATTACHED

Figure 13. Completion of rack/dolly conversion.

A. Submersible pump dolly.

B. Cable reel dolly.

Figure 14. Pump and cable reel dollies.



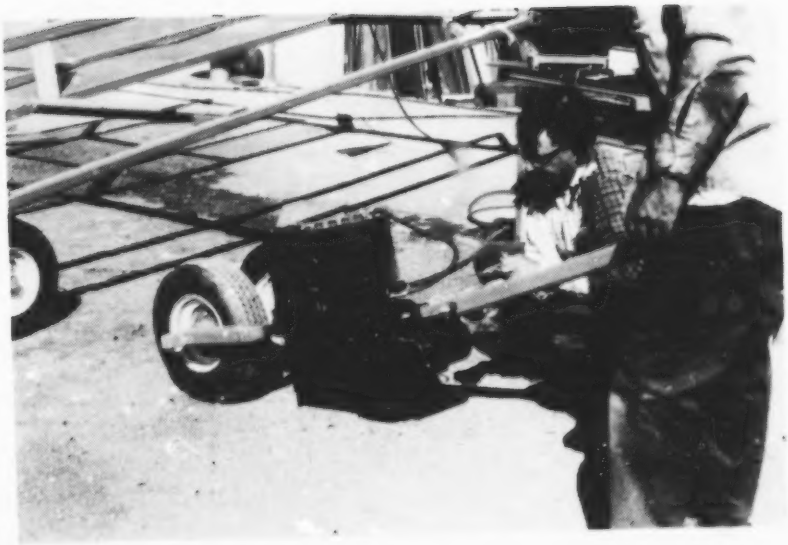


Figure 15. Winch dolly.

For setting up the system at night, each unit is equipped with two 1500-watt floodlights (see Figure 16). These floodlights mount on the shear wall stanchions welded to the booster skids (see Figure 17B) that are used to secure the pipe and pipe and fitting racks (both fore and aft) in transit. Onsite, the crossarms (already removed from the rear stanchion in Figure 17B) that secure each of these racks to the stanchions may be removed, turned 90^0, and by means of adapters (carried in the tool box) mounted to the stanchion to provide an additional 1.2 m (4 ft) of height above the trailer deck for the lights. The floodlights are mounted with two degrees of freedom in rotation so that lights can be provided in any direction.

A 107-meter (350-ft) service cord for one floodlight enables it to be moved anywhere between the staging point and the stream, so that whenever difficult terrain is encountered in night operations, ample lighting will be available for setting up the submersible pumps, power cables, upstream piping, and pump on-off and alarm switches.

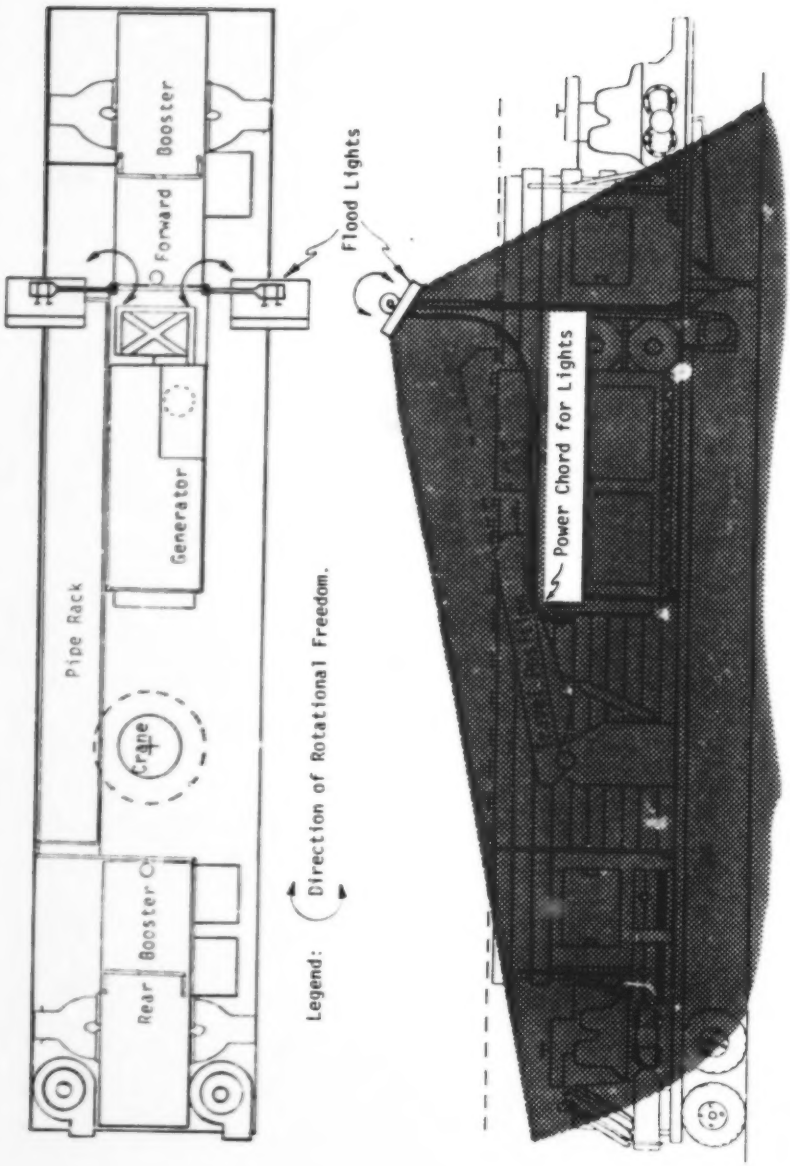
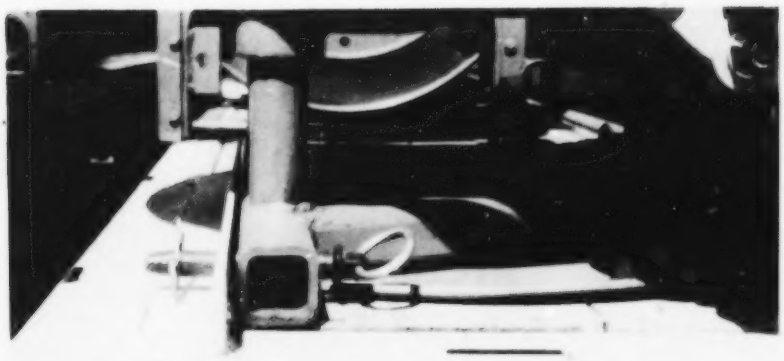


Figure 16. Floodlight mounting stations.



A. Submersible pump retaining pin.

B. Pipe rack retaining pins in rear stanchion.

Figure 17. Quick-release retaining pins.

SECTION 5

SYSTEM OPERATION

Efficient application of the stream diversion system will require experience, and attention to development of standard management strategies as a backlog of experience is acquired. Until that experience is acquired, some discussion of approaches to efficient application and to pumping options is included here. Figure 18 illustrates the deployment of the MSDS in a typical spill scenario.

Assuming notification of a spill has been received, an effective management approach would be to dispatch the foreman to the site by the fastest means in order to select and mark the staging area for the drivers and to identify any existing or potential problems. The foreman of the MSDS should also provide decision information on selection of sites for catch basins, etc. Under ideal conditions, only the stream velocity, elapsed time from spill to completion of the downstream dam, and the margin for error allotted to these two estimates will determine the length of stream to be isolated. However, because a catch basin cannot be infinite, the length to be isolated will be affected by how rapidly the upper basin (above the isolated region) fills. Hence, isolated length also depends on the volume rate of flow of the stream and the choice of catch-basin site (i.e., on catch-basin volume). It should be the MSDS foreman's task to temper site selection by knowledge of the time it will take to get the MSDS in operation, taking local conditions into account, as well as which mode of operation should be employed.

To help in the decision process, the capability of MSDS under different conditions (modes) of operation must be known. Table 3 lists a number of operational modes for the system. These have been computed based on the assumption that the pipe is laid over level ground and that the pump pressure acts only against head loss in the pipe. Under such circumstances the booster pumps are not required for the system to deliver a flow volume of 0.35 m^3/s (5,600 gpm) a distance of 0.3 km (1,000 ft) as this is within the capability of the submersible pumps. Under these assumption, it is also within the capability of the system to deliver 0.07 m^3/s (1,100 gpm) a distance of 0.9 km (3,000 ft) with just the submersible pumps (0.09 m^3/s [1,425 gpm] with one submersible and one booster pump).

There are definite benefits to be gained if a mode can be selected which eliminates the requirement for a booster pump (because the boosters on each unit use four times the fuel required to operate the submersibles). Thus, a judicious choice of operational mode can save fuel, reduce operational costs,

Figure 18. MSDS spill application.

TABLE 3. MOBILE STREAM DIVERSION SYSTEM (MSDS) OPERATIONAL MODES

Mode	Volume Flow Rate @ .3 km Q (m^3/s)	Volume Flow Rate @ .3 km Q (gpm)	Volume Flow Rate @ .6 km Q (m^3/s)	Volume Flow Rate @ .6 km Q (gpm)	Volume Flow Rate @ .9 km Q (m^3/s)	Volume Flow Rate @ .9 km Q (gpm)	If Series Staged With Additional Pipe: Stages	Q (m^3/s)	Q (gpm)	Range km	Range ft	Pipe Required km	Pipe Required ft
1. (S)—	.11	1,750	.09	1,425	.06	950	4	.09	1,425	2.4	7,900	2.4	7,900
2. (S)(S)—	.22	3,500					2	.18	2,900	1.2	3,900	2.4	7,900
3. (S)(S)(S)—	.18	2,900	.10	1,600	.07	1,100							
4. (S)(S)(S)—	.35	5,600					1	.10	1,600	0.6	2,000	1.2	3,950
5 (S)—[B]—	.10	1,600	.10	1,600	.09	1,425	4	.09	1,425	11	36,000	11	36,000
6. (S)(S)—[B]—	.20	3,200					2	.18	2,900	5	16,400	11	36,000
7. (S)(S)(S)—[B]—	.18	2,900	.18	2,900	.11	1,750							
8. (S)(S)(S)—[B]—	.35	5,600					1	.35	5,600	1.1	3,600	2.2	7,200

Note: Submersible pumps (S) and booster pumps [B] may be used singly or jointly, in series or parallel, with individual or common pipelines. The mode symbols used are descriptive of such arrays. Volume rate of flow for the system has been indicated for the two specified and one intermediate distance in the left-hand columns, possible future options in the right.

and cut down on air pollution. Where it is necessary to deliver flow up a hill or at a great distance (and high frictional head loss) the booster pumps may be absolutely necessary. However, an alternative to higher pumping pressure is to stage several pumps along the pipeline. This requires that small reservoirs, e.g., inflatable swimming pools (not part of the present system), be provided as sumps, one for each successive submersible pump. A pool about 1.5 m (5 ft) in diameter and 0.5 m (1.5 ft) high is sufficient. With this artifice, total dynamic head capability of the submersible pumps alone becomes 73 m (250 ft) at 0.9 m^3/s (1,425 gpm) and TDH of the entire system becomes 408 m (1,350 ft) at this volume flow rate. To achieve the maximum TDH, each prior stage booster would fill the reservoir supplying the next stage submersible pump, with one sumbersible servicing each booster. (A staged system of this sort could actually deliver 0.09 m^3/s (1,425 gpm) a distance of 11 km (7 mi), or 0.18 m^3/s (2,900 gpm) a distance of 5 km (3 mi) over level ground.) Without staging, the present TDH capability is 102 m (334 ft) at 0.09 m^3/s (1,425 gpm).